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Thermomechanical Modeling of Counter-Flow Packed-Bed Particle-to-sCO2 Heat Exchangers

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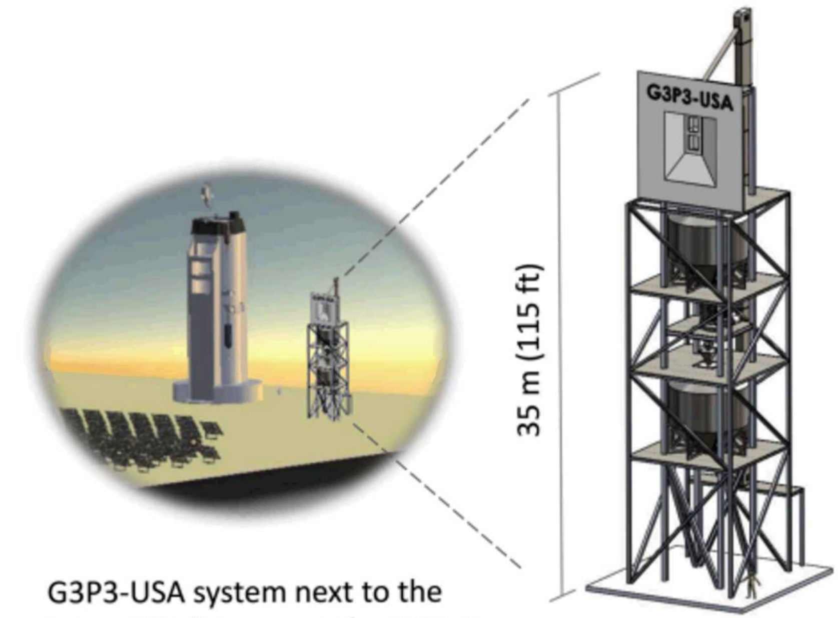
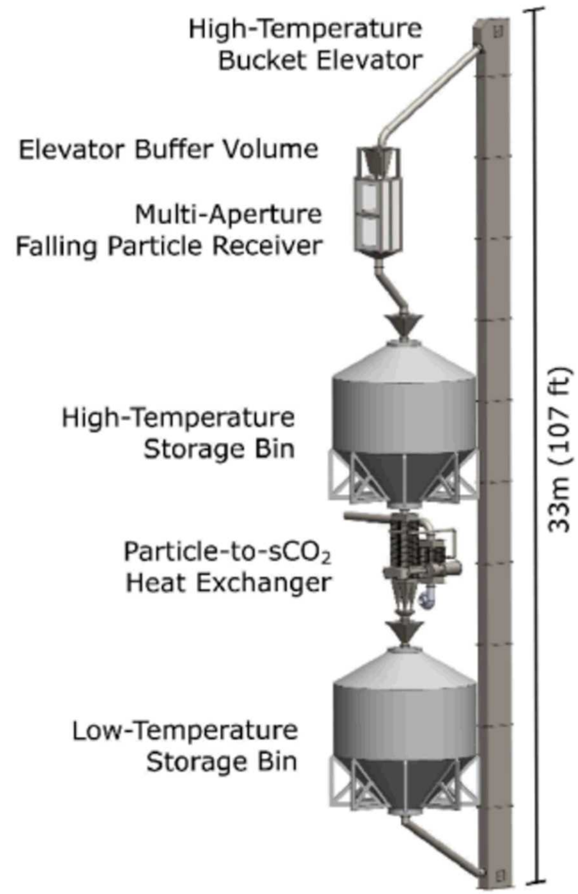
Particle-sCO2 Solar Power Plant

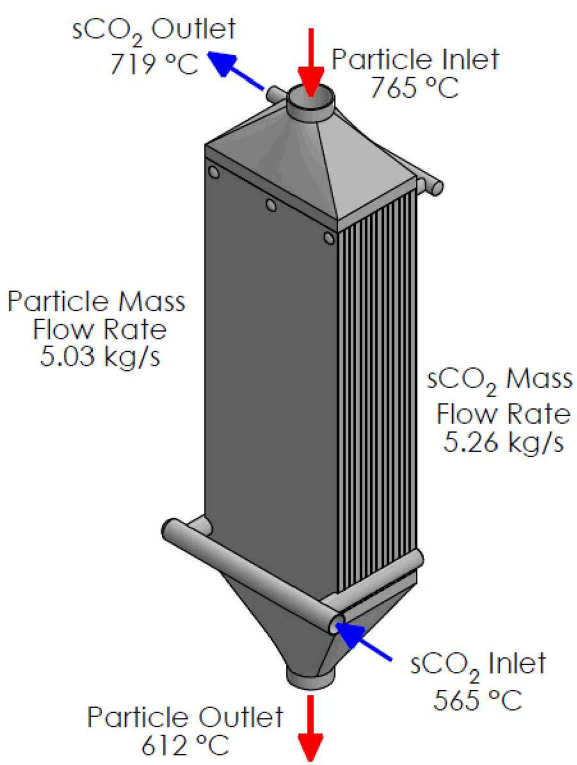


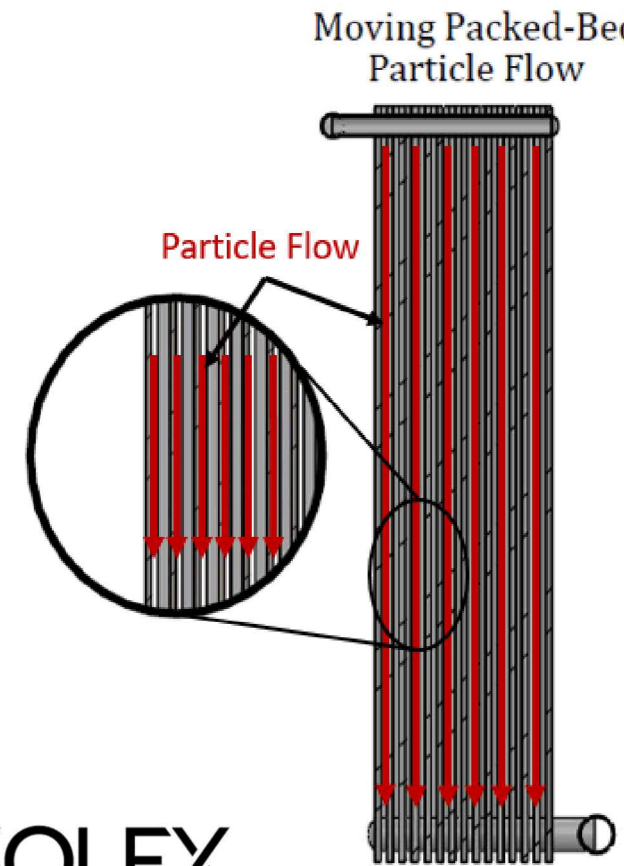
G3P3-USA system next to the existing 200-ft tower at the NSTTF

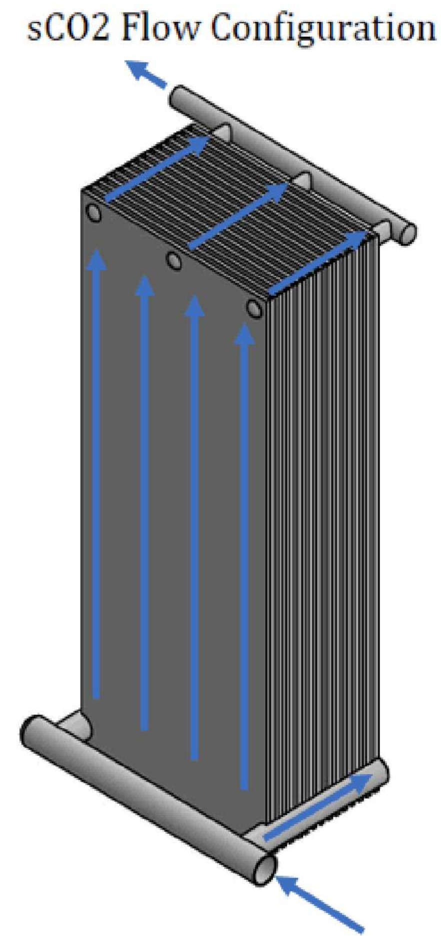


- High temperature-stable particles enable the use of a high efficiency sCO2 Brayton cycle.
- The performance of the particle-sCO2 heat exchanger is crucial to the levelized cost of electricity.

Particle-sCO2 Heat Exchanger Design





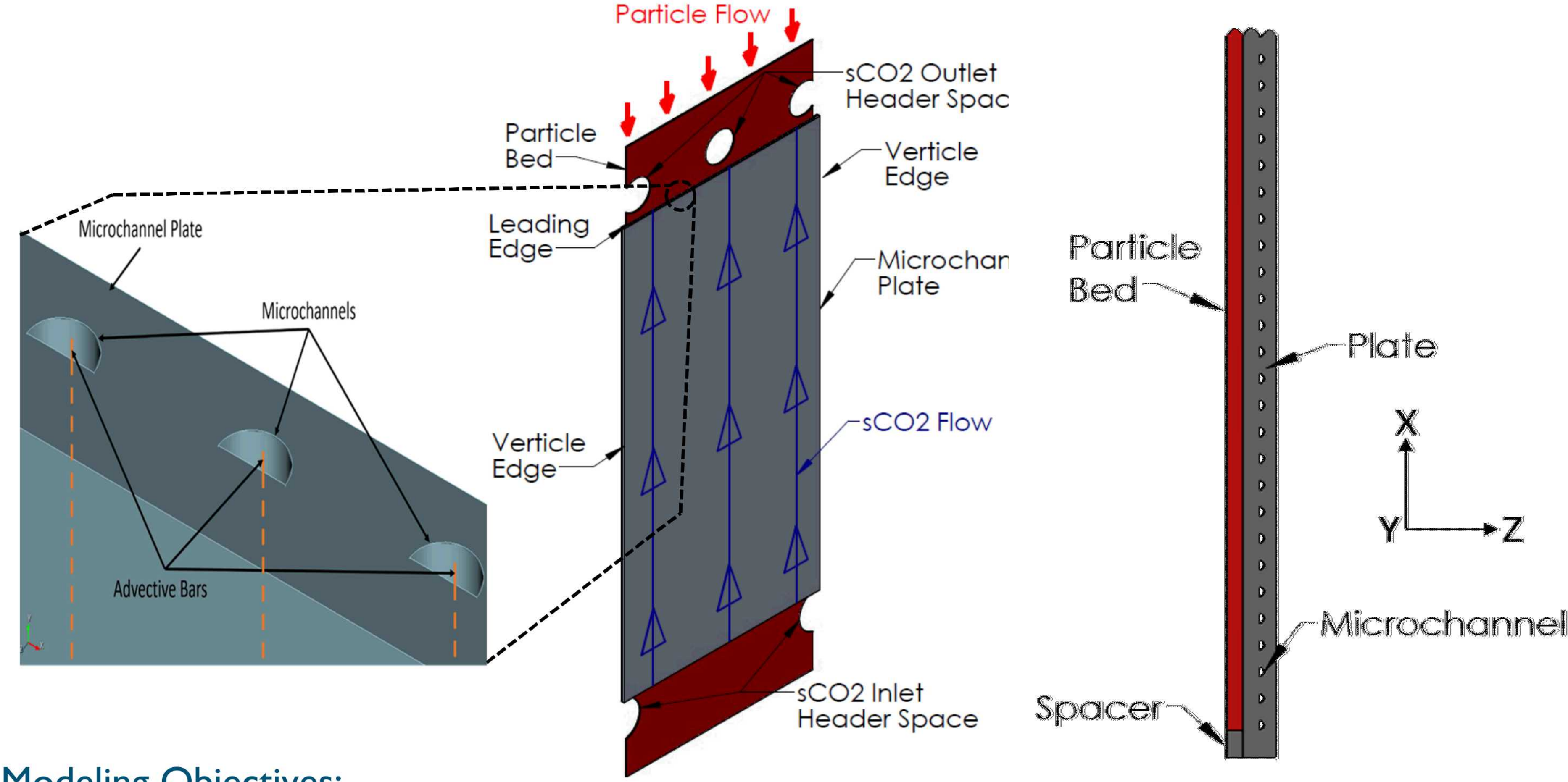


VPE VACUUM PROCESS ENGINEERING

SOLEX THERMAL SCIENCE

- Design of a 1 MW_{th} particle-sCO_2 heat exchanger for the G3P3 Particle Pilot Plant.
- The performance, sizing, and start-up procedure for the heat exchanger was determined.

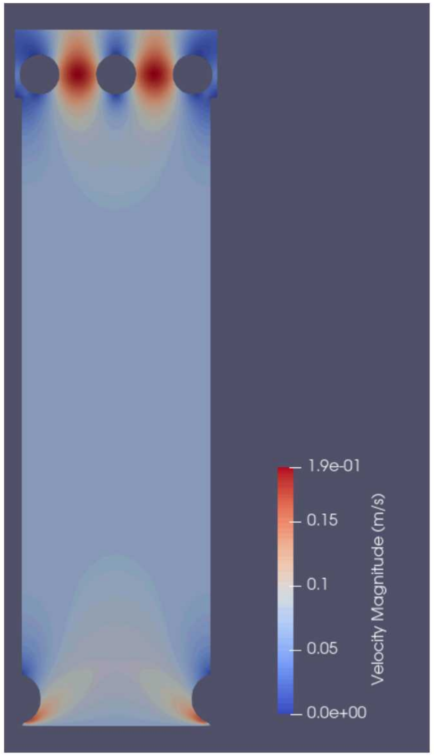
Particle-sCO2 Heat Exchanger Model



Modeling Objectives:

- Determine thermal performance via the overall heat transfer coefficient (U).
- Calculate the number of microchannel plates required for a 1 MWth thermal duty.
- Establish a start-up procedure which does not create stresses outside the allowable range.

Steady State Results



Particle Bed Velocity

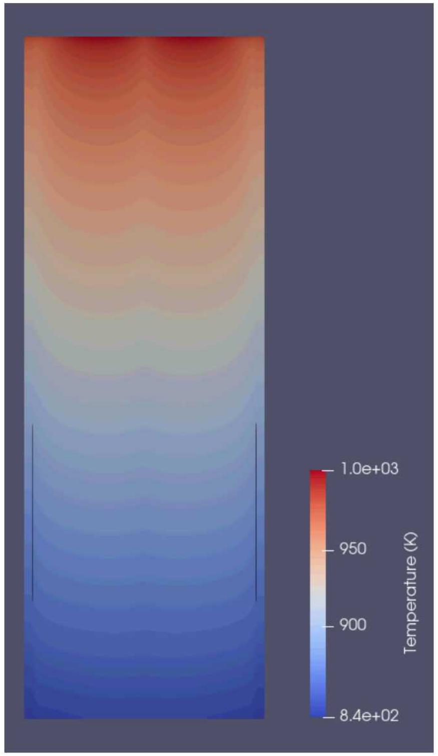


Plate Temperature

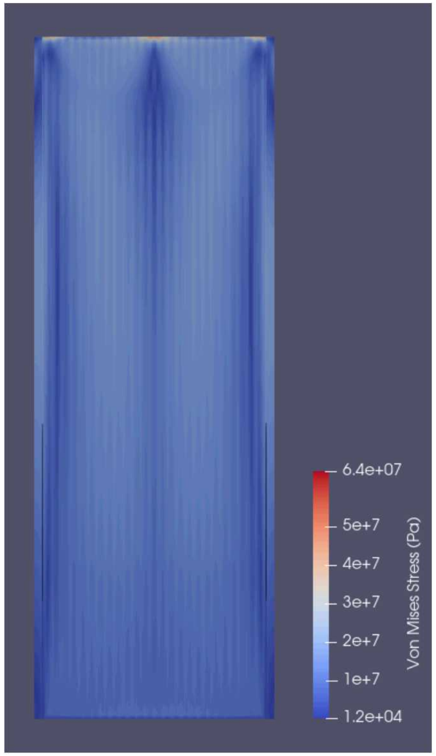


Plate Stress

- Adding the particle flow around the headers reduced U by less than 1%.
- The overall heat transfer coefficient was determined to be 434.47 W/m^2-K, an improvement from 167 W/m^2-K [1] for a cross-flow heat exchanger design.
- The number of 0.58 m wide, 1.28 m tall plates required for a 1 MW_{th} thermal duty was 35.

[1] Albrecht, K. J. and Ho, C. "Heat Transfer Models of Moving Packed Bed Particle to sCO 2 Heat Exchangers," Power Energy (2017).

Particle Mass Flow Rate Ramping

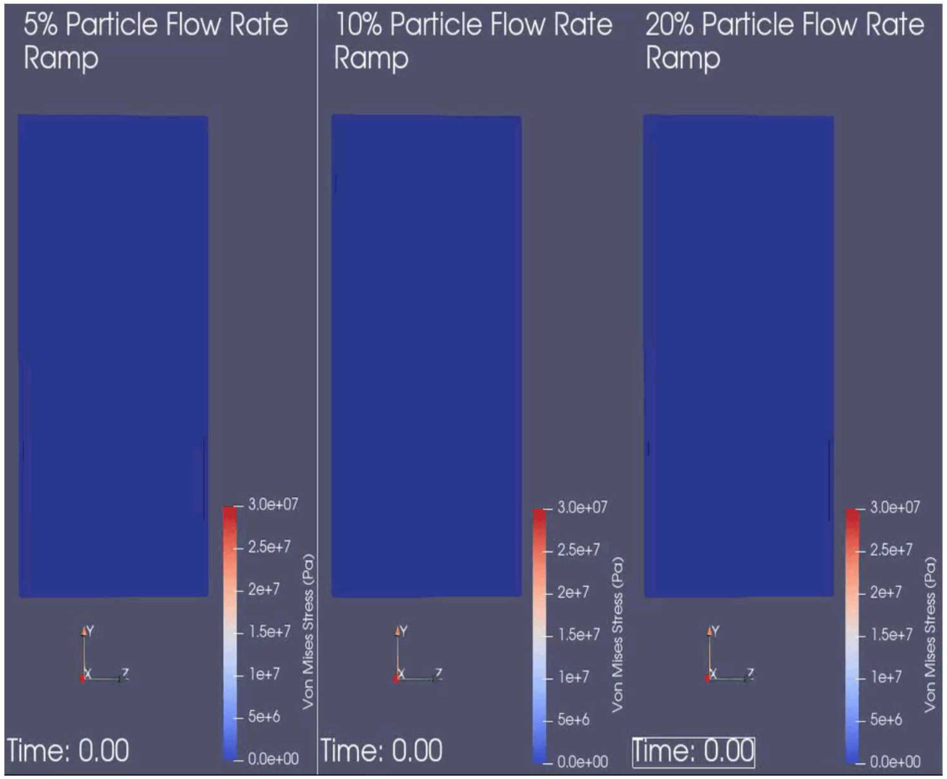
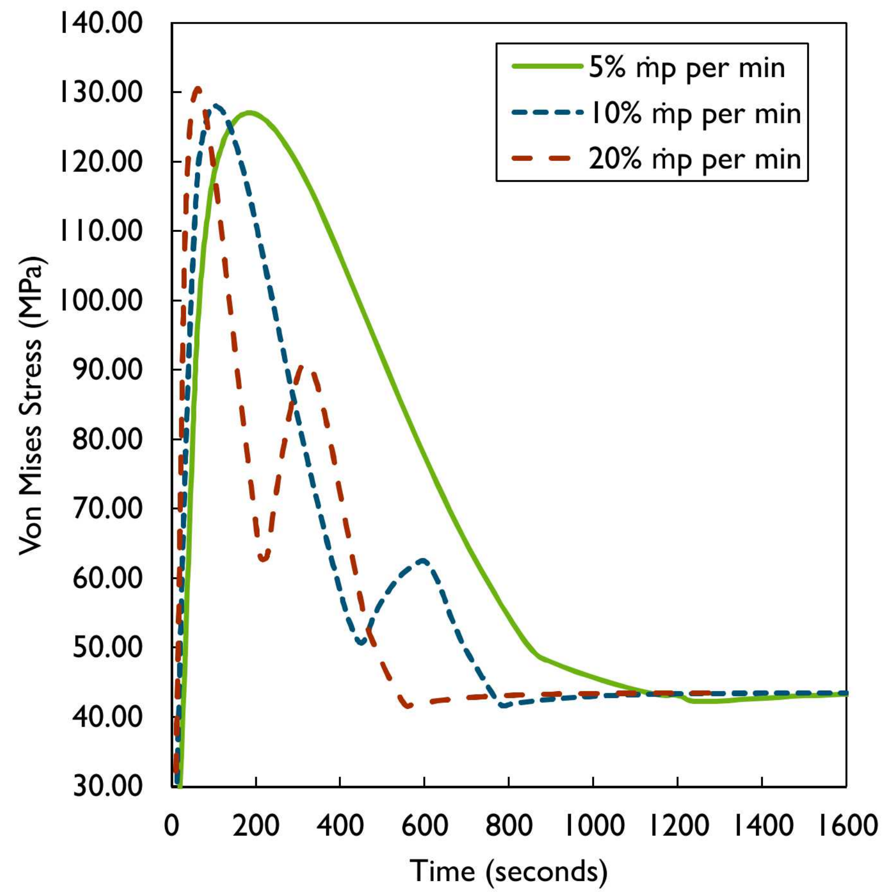


Plate Stress During Start-Up



- The particle flow rate was increased at various rates until the target flow rate was reached.
- The heat exchanger was initially set to the target inlet temperature of the sCO_2.
- All flow rate ramps caused a peak stress around 130 MPa, well above the allowable stress.

Particle Temperature Ramping

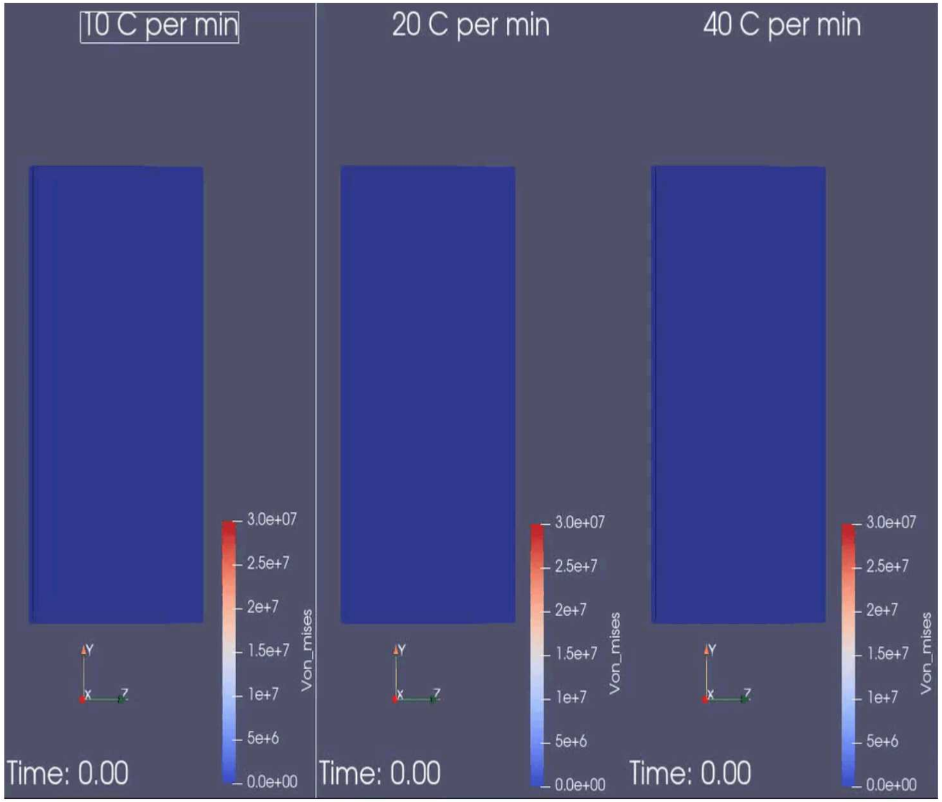
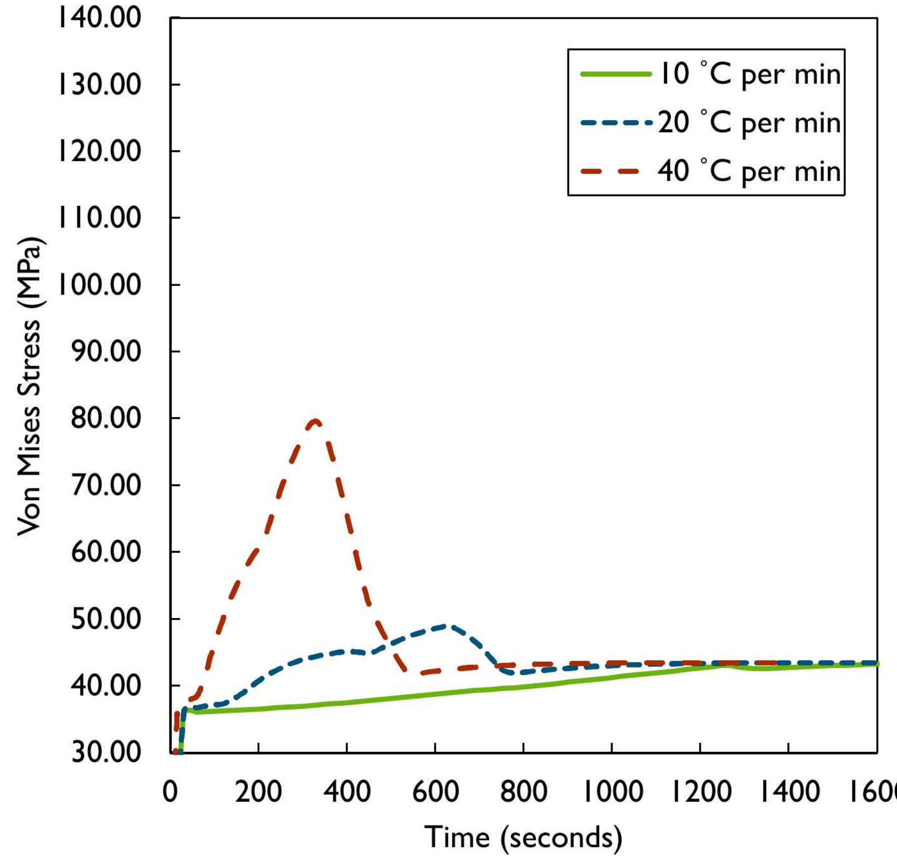
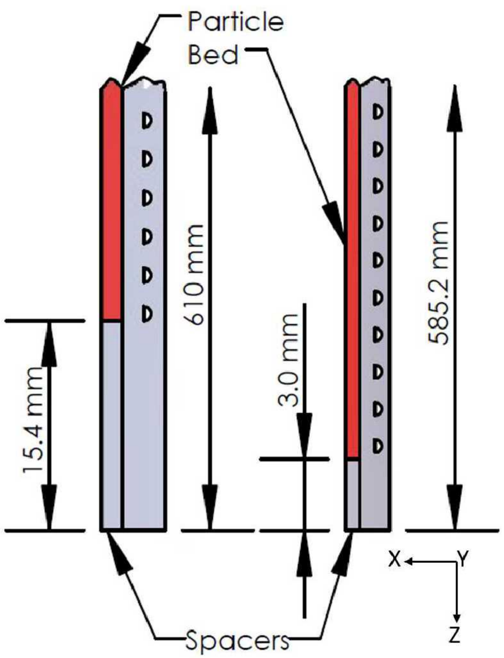


Plate Stress During Start-Up



- The particle inlet temp. was increased at various rates until the target temp. was reached.
- The heat exchanger was initially set to the target inlet temperature of the sCO_2.
- All temperature ramps caused less peak stress than the flow rate ramps.

Plate Vertical Edge Effects



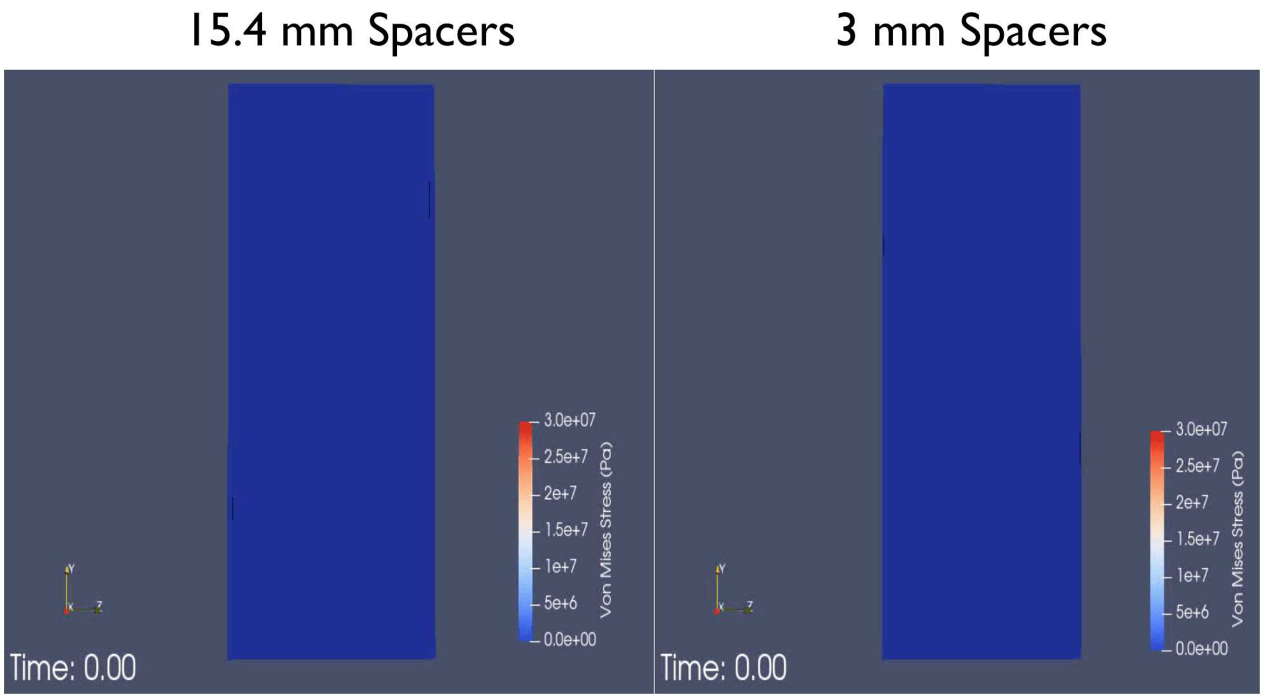
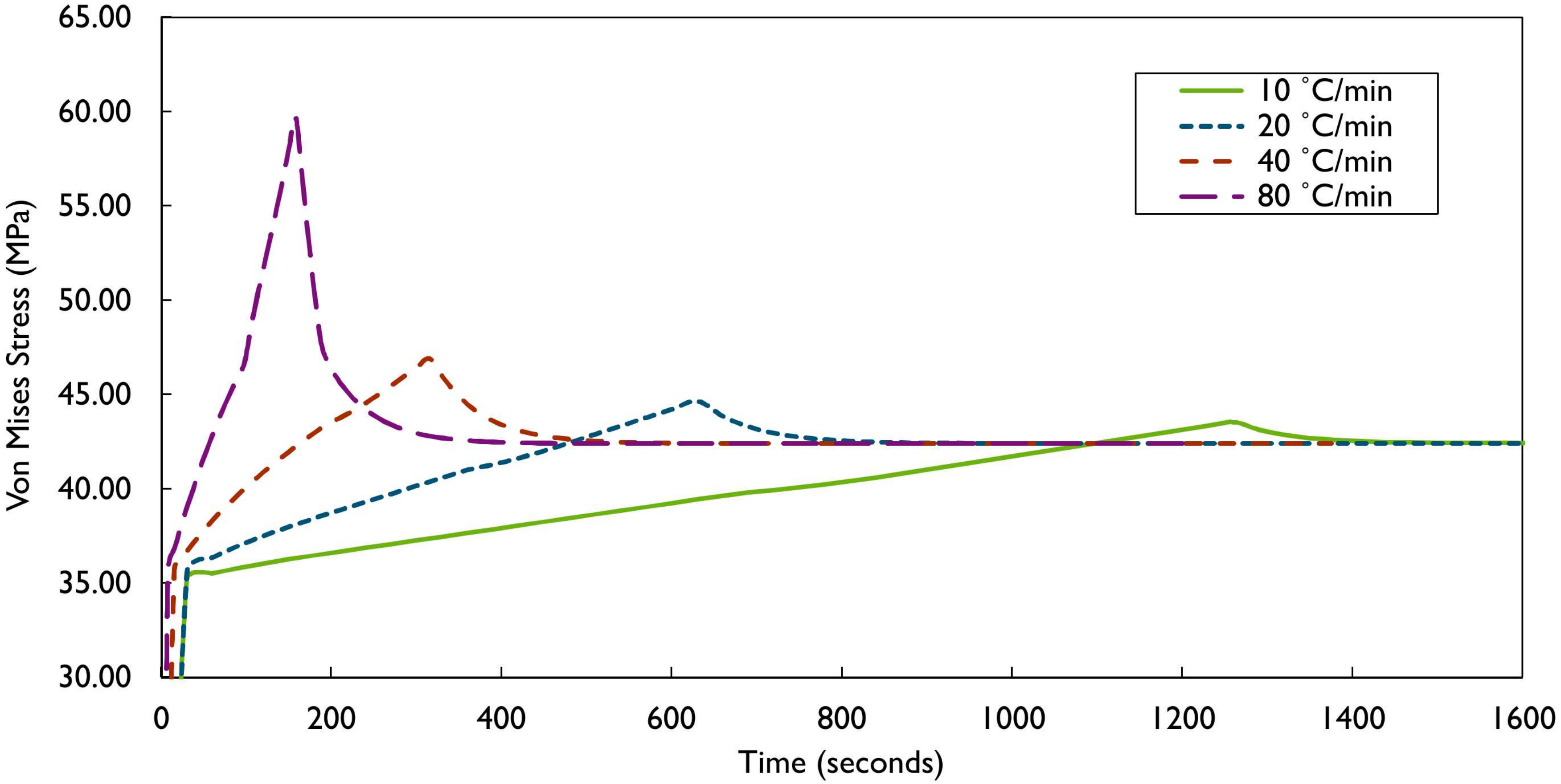


Plate Stress During Start-Up

- Initially the plate's design had a 15.4 mm space from the edge of the plate to the 1st channel.
- This space at the sides of the plate caused areas of high stress during start-up.
- Reducing this space to 3 mm decreased the stress on the sides of the plate significantly.

Start-Up Procedure Analysis



- The particle inlet temperature ramps were then applied to the heat exchanger with 3 mm spacers.
- The spacers' peak stress reduced significantly when the spacers were reduced to 3mm.

Start-Up Procedure Analysis

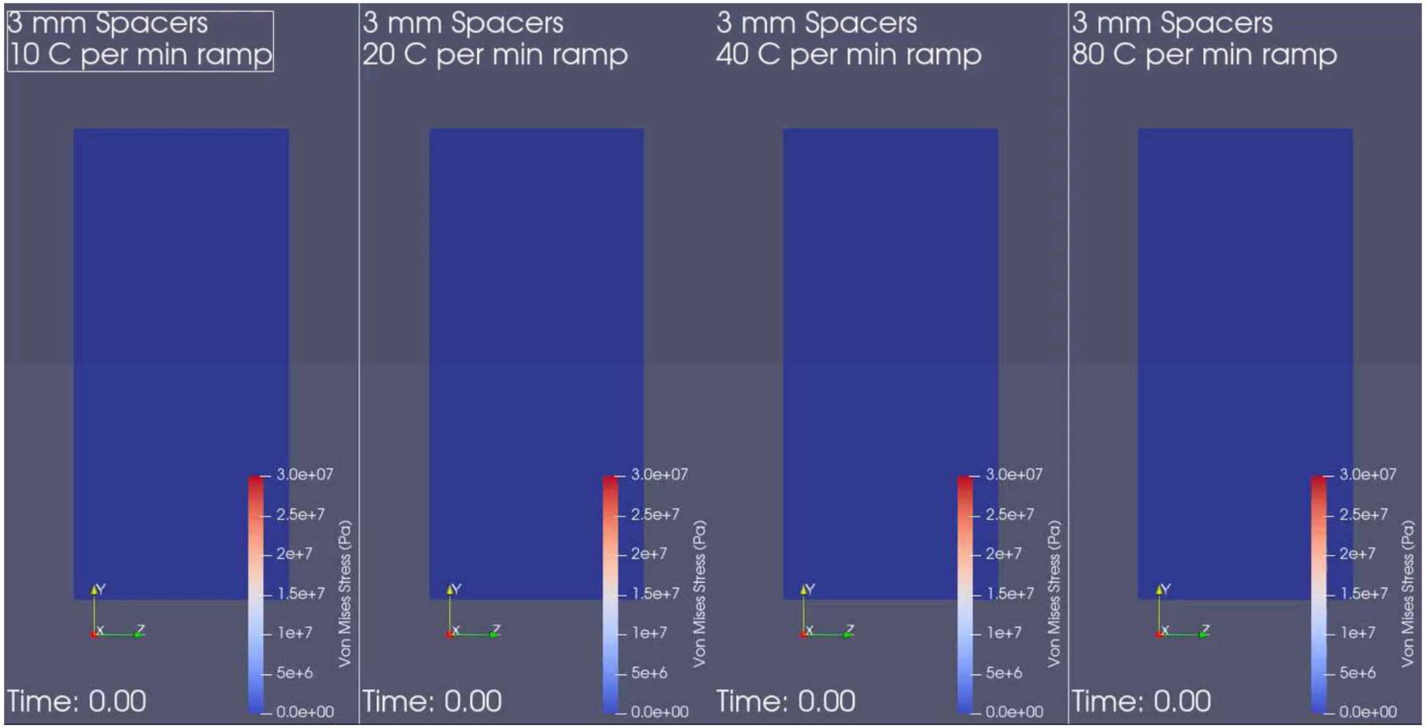


Plate Stress During Start-Up

- The particle inlet temperature ramps were then applied to the design with 3 mm spacers.
- A 20 °C per minute ramp was determined as the quickest start-up procedure to stay under the allowable stress on the vertical sides.

Conclusions

- Key factors found in the modeling of this heat exchanger:
  - Around 160% increase in U for counter-flow from cross-flow HX.
  - Areas within the plate without bad thermal communication cause high stress.
  - Temperature ramps induced less stress than flow rate ramps.
- Further model development:
  - Implement a CFD analysis of the sCO2 flow through microchannel plate.
  - Investigate stress around microchannels with refined mesh.

ACKNOWLEDGEMENTS

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